

Addressing the Regression Test Problem with Change Impact Analysis for Ada*

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Abstract. The *regression test selection problem*—selecting a subset of a test-suite given a change—has been studied widely over the past two decades. However, the problem has seen little attention when constrained to high-criticality developments and where a “safe” selection of tests need to be chosen. Further, no practical approaches have been presented for the programming language Ada. In this paper, we introduce an approach to solving the selection problem given a combination of both static and dynamic data for a program and a change-set. We present a *change impact analysis* for Ada that selects the safe set of tests that need to be re-executed to ensure no regressions. We have implemented the approach in the commercial, unit-testing tool VectorCAST, and validated it on a number of open-source examples. On an example of a fully-functioning Ada implementation of a DNS server (IRONSIDES), the experimental results show a 97% reduction in test-case execution.

Keywords: Ada; change impact analysis; regression testing; unit testing; test-case selection; code coverage; change-based testing; safety-critical software

1 Introduction

In their seminal work of 1988 [5], Harrold & Soffa introduced a dataflow-based approach for minimising the regression test effort in the context of Pascal. Since then, the problem of regression test execution has seen considerable attention [3,12,22].

Furthermore, and given the recent emergence of agile processes [24], which promote test-driven development as well as continuous integration [9], there is now a desire from developers to be able to re-test modified software rapidly. However, in the context of Ada, there are few articles (to the best of our knowledge, there only exists one paper [13] from 1997 that investigates change impact analysis for Ada) discussing how to solve the problem, without reverting to “retest all” [17].

Consequently, this paper considers the *test-case selection problem* [3]:

“determine which test-cases need to be re-executed [...] in order to verify the behaviour of modified software”

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when applied to systems developed using Ada. It follows that we aim to investigate the plausibility of applying change impact analysis to regression testing of Ada source code. To this end, we seek to minimise the number of tests a developer needs to re-execute to determine if the behaviour of their software has been affected after making a change.

Our approach for *change-based testing* (CBT) of Ada is as follows. We begin by assuming the existence of a test baseline \mathcal{T} of regression tests associated with a set of Ada source files, as well as access to both the original and modified source code. The analysis then proceeds as follows:

1. The difference between the original and modified source code is assessed to construct a *change-set* \mathcal{A} . This change-set encapsulates changes at the interface, package and subprogram¹ levels.
2. An intermediate representation of the program is constructed, based on both static data (derived without executing the program) and dynamic data (collected by executing the existing test baseline \mathcal{T}). This intermediate representation forms the basis of a dependency graph of the Ada source code.
3. Given the change-set \mathcal{A} and the intermediate representation, we determine a set of tests $\mathcal{T}' \subseteq \mathcal{T}$ that is affected by the changes in \mathcal{A} . We use the internals of the test automation tool VectorCAST to calculate the correspondence between changes in \mathcal{A} and the dependency graph.

In Step 1, we are concerned with the calculation of the subset of packages and subprograms that were modified by a given change-set. Step 2 is focused on establishing the set of interdependencies in the software. Finally, Step 3 is concerned with the identification of those tests whose behaviour was affected from the data in Step 1. As we demonstrate later, we consider the locality (i.e., specification vs. body vs. subprogram) of the change to allow us to accurately understand its change-impact.

To-date, approaches to performing a change impact analysis for object-oriented languages either consider a static or a dynamic-derived dependency graph [3,12,22]. Uniquely, we consider a hybrid approach, using data from both static and dynamic analyses. Our change impact analysis calculates three types of dependency:

- Statically:
 1. Type and Ada specification dependencies – where Package A depends on Package B as part of A’s specification
 2. Uses and Ada body dependencies – where Package A depends on Package B as part of A’s body
- Dynamically:
 3. Subprogram invocation and coupling – where a subprogram Foo in Package A calls a subprogram Bar in Package B

Considering dependency data that is derived both statically and dynamically results in a technique that is not exclusively tied to subprogram-level analysis [16]. That is, we can consider the change impact at different levels of the software architecture. For example, it can support changes that occur at package-scope or to the object hierarchy.

¹In this paper, we use the term “subprogram”, without introducing ambiguity, to refer to either a function or a procedure inside of an Ada package.

Approaches based on static slicing [10] of the program are often overly-conservative, while maintaining “safety” [11]. When developing safety-critical systems, it can be accepted that this conservatism is of benefit, as it accounts for all possible behaviours of the system. However, this can lead to a change impact analysis that results in the (undesirable) “retest all” answer, which can be of little use to developers wishing to verify their day-to-day work.

Conversely, dynamic slicing (e.g., an analysis based on collected code coverage), considers only the behaviours and impacts that have been observed as part of previous system executions. An analysis based purely on dynamic data will potentially lead to “unsafe” conclusions [11].

We describe our approach as *safe* – by this, we mean that any test contained within “impact set” is *at least necessary* to exercise all of the impacts of the changes in a given change-set. Our work also aims for *minimality*, but not the *minimal* test-case set. Minimality cannot be achieved without a heavier approach to the change-impact process. For example, a finer-grained analysis could be based on modifications to the *def-use chains* [7] for package-level variables, and subsequently only execute those tests that depend on those variables.

We note that, basing the analysis (partly) on code coverage allows us to avoid complications when it comes to Ada 83 features such as generics, or Ada 95 features such as dynamic binding [1]. If the internals of a subprogram change invoke another (late-bound) subprogram, this would be detected as a subprogram-level change. Consequently, all tests executing that subprogram would be re-executed, invoking the newly added dynamic call. As such, there is no need to adopt a heavier approach that needs to consider polymorphism [17]. We discuss this further in Section 3.5.

Structure of the paper. The rest of the paper is structured as follows. In the immediate subsection (Section 1.1), we provide an overview of the relevant literature to the regression test problem. The subsequent section (§2) provides a brief introduction to software change impact analysis and VectorCAST. In Section 3, we introduce our approach to impact analysis for Ada. We then provide an experimental evaluation (Section 4), based on a selection of open-source examples. In the final section (§5), we conclude.

1.1 Related Work

In 1988, Harrold & Saffa [5] introduced an *incremental testing* methodology for Pascal. To achieve this, they associated a test with the path taken through a module. The “incremental tester” would then try to re-use test-cases by identifying the tests that exercise the changes, or those which had their execution path modified by the change.

Loyall *et al.* [13], implemented a prototype impact analyser that presents the static dependency graph in a hyperlinked form to allow for easy navigation. While their tool does support Ada, it does not actually calculate the impact of a change in the source code – it is designed to support a “what if” approach to potential changes. A user can select an entity that might be modified, and then see the effects of this modification.

In [20], Ren *et al.* introduce the tool *Chianti*, which is able to calculate the set of affecting changes in a Java program that can lead to the behaviour of a test being

modified. They consider two approaches: one based on static call graphs, and one based on dynamic call graphs. However, they do not consider the combination of static and dynamic data for a more precise analysis.

The theoretical underpinnings of *Chianti* were presented in [21], where the classification of *types* of (atomic) changes in Java programs was introduced. An approach was then designed to calculate the impact on other areas of the system, given a collection of atomic changes.

Law *et al.* [11] consider the application of dynamic program slicing to the change impact process. Their approach is focused on the affect of program modifications on other parts of the program, rather than the test-case minimisation problem. They present the algorithm *PathImpact* that decides if a change in procedure p of a program P has a potential impact on other procedures reachable from p in the call graph G of P . *PathImpact* then calculates a forward and backwards slice through the program, as well as tracking function calls and returns, such that a backwards analysis is accurately scoped. In [15], Orso *et al.* present the *CoverageImpact* algorithm, which walks the execution data in combination with a forward slice of the variables in the program to calculate the impacted set. This set is then used to identify the tests that should be re-executed.

2 Background

We briefly introduce *change impact analysis* (Section 2.1) and VectorCAST (Section 2.2).

2.1 Software Change Impact Analysis

Simply put, software change impact analysis [19] is a family of techniques for determining the effects and outcomes of a source code modification, and for improving developer productivity in the context of such a change. We refer the interested reader to [3,12].

We illustrate the outcome of a potential change in Figure 1. For example, consider a change to Package C in the source tree shown. We will have two types of impact:

Upstream changes – this is where Package A calls into Package C. A modification to either the internal behaviour or external interface to Package C can cause a potential change in Package A.

Downstream changes – this is where Package C calls into Package F. While the internal behaviour of Package F cannot be affected by this change (Package F can be oblivious to Package C), Package F may now be used in a different way.

In the context of this paper, we are interested in identifying the set of tests that must be re-run in the presence of a change to Package C. To elucidate, any tests that execute directly on C would have to be re-run (depending on the scope of the change) and any tests associated with units (e.g., A) that have code coverage on the modified parts of C should also be re-run. We exclude re-executing the tests for Package F, as the tests on Package C, which collect coverage on F already, will validate this modified use of F.

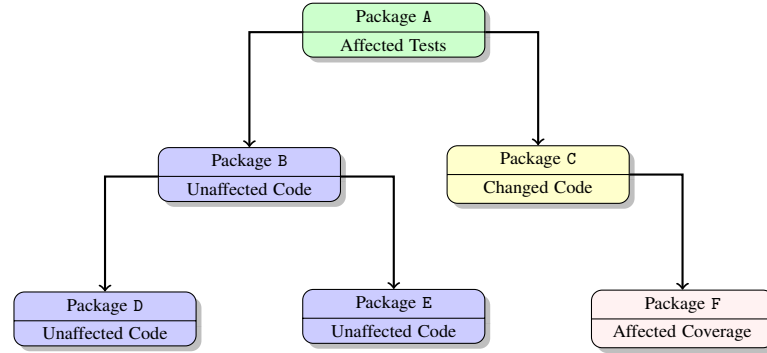


Fig. 1: How changes can propagate through the source tree

2.2 VectorCAST

VectorCAST/Ada² is a commercial, dynamic unit testing and code coverage tool for Ada. To construct automatically unit testing environments for Ada source code, VectorCAST parses the provided Ada program, extracts the relevant Ada types/packages, and then presents a “test-case designer” that allows a user to specify tests without the need to write tests in Ada directly. Crucially, VectorCAST is also able to instrument the source code to obtain code coverage from test case execution.

Following [18], we note that unit testing environments can be constructed in two ways:

- A “unit test” mode, where testing is performed on an individual unit, where all of its external dependants have been automatically mocked [18].
- An “integration test” mode, where testing can be performed across multiple units, and where the external dependants have been brought into VectorCAST and can be instrumented for code coverage. In this mode, the behaviour of the external interfaces (via expected call and return values) can also be tested.

With the exception of a change to a dependant specification, change-based testing in unit testing mode is limited to selecting the tests to re-run inside of a single unit. Change impact analysis is more complex when you consider integration-style tests, as there will be dependencies between the units contained inside the testing project. The test selection problem is then to minimise the re-test effort, in the context of changes in any dependants.

3 Change-based Testing for Ada

We now present our approach for performing impact analysis and solving the test-case selection problem for Ada.

We consider a “safe” approach to change impact analysis at the expense of false negatives: in the context of a safety-critical software development, we consider it more appropriate to have an overzealous change impact, rather than exclude a test erroneously (false positives).

²www.vectorcast.com; in what follows, we write VectorCAST to mean VectorCAST/Ada

3.1 Dynamic Impact Analysis

The high-level of a typical *dynamic-only* impact analysis [12] is shown in Figure 2. In this figure, we see that the “core” of a dynamic impact analysis approach is the ability to map test data to run-time data, therefore allowing us to calculate those tests effected. To support processing the change set into an impact set, we assumed that the relationship between this data is stored internally in the tool: the *intermediate representation*.

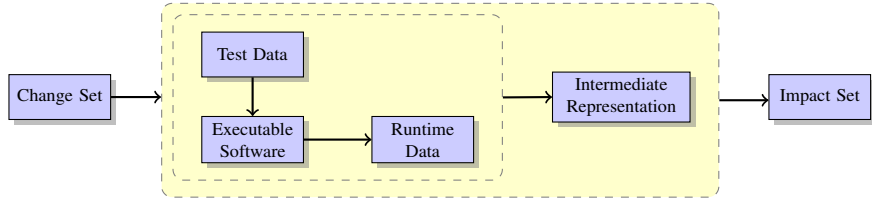


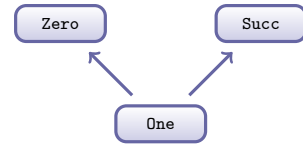
Fig. 2: Strictly dynamic change impact analysis

The intermediate representation can take a number of forms when considering a dynamic analysis. When considering code coverage-based analyses with information derived from test execution, such information can be stored as a dynamic dependency tree. For the Ada program shown in Figure 3a, we exemplify its dynamic-only dependency tree in Figure 3b. A change in either Zero or Succ may affect the behaviour of One.

```

1  package body Peano is
2
3      function One return Integer is
4      begin
5          return Succ(Zero);
6      end One;
7
8      function Zero return Integer is
9      begin
10         return 0;
11     end Zero;
12
13     function Succ (Val : in Integer)
14     return Integer is
15     begin
16         return Val + 1;
17     end Succ;
18
19 end Peano;
```

(a) A trivial Ada program



(b) Dynamic dependencies

Fig. 3: Example dependencies

We presume the existence of an original program P and a modified program P' , which has been derived from P . Furthermore, it is also assumed that both P and P' are both syntactically and semantically correct (i.e., compilable). The analysis places no restriction beyond these on the nature of the changes.

In the context of what follows, we assume that the intermediate representation contains both static and dynamic data, and the availability of information about the packages (specifications and bodies) and subprograms that have been altered.

3.2 Intermediate Representation for Ada

We now introduce the data structures used to construct our analysis for Ada. As we are developing a hybrid approach using both static and dynamic data, we introduce both separately.

Static Data. For the data we wish to extract statically from the Ada program, we consider the following data-types:

$$\begin{aligned} \textit{Contains} &: \textit{Package} \rightarrow \textit{Subprogram}^* \\ \textit{Uses} &: \textit{Package} \times \{\textit{Body}, \textit{Spec}\} \rightarrow \textit{Package}^* \end{aligned}$$

The data structure *Contains* is used to map Ada *Packages* to zero-or-more *Subprograms* contained within that *Package*. Similarly, *Uses* creates a dependency map between *Package* body and specifications, to the package specifications that they “with”.

We use the relation *Contains* to find all affected subprograms given either a specification or a package body-level change; *Uses* allows us to track when a dependant has been modified (e.g., if package A withs B, and if B changes, we know that we need to re-execute any test covering package A).

For the presentation that follows, we assume that it is possible to compute the inverse of *Contains* and *Uses*.

Dynamic Data. We now consider the dynamic data we require for our analysis:

$$\textit{Covers} : \textit{Test} \rightarrow \textit{Subprogram}^*$$

which maps test-cases in the test baseline, \mathcal{T} , to the subprograms covered when a given test is executed. We note that, unlike [11,16], we are not concerned with the ordering of subprogram calls/returns for a given test.

It is clear that, when combining these tree-like data structures, it is possible to construct a combined, static/dynamic dependency tree. Such a tree could be unfolded to construct a directed, acyclic dependency graph of the program. This is because dependency relationships between entities are transitive. That is, if A depends on B and B depends on C in one or more dependency relationships, then A depends on C.

3.3 Example

Before presenting the approach to solve the test-case selection problem, we exemplify the technique when applied to Ada source code. We illustrate the process using the small Ada program shown in Figure 4.

In this example, we have two packages (A and B), each containing a single function. In the body of package A, we have an external dependency on the specification of B, via the use of the “with” directive. It is clear that there is an implicit dependency between each package and its specification (i.e., that the body of A depends on the specification of A). It follows that we have $A \times \text{Body} \rightarrow B$ in *Uses*, and $A \rightarrow \text{Foo}$ in *Contains*.

```

1  package A is
2
3      function Foo
4          return Integer;
5
6  end A;
```

(a) Package Specification for A

```

1  with B;
2
3  package body A is
4
5      Qux : Integer;
6
7      function Foo return Integer is
8      begin
9          return Qux + B.Bar;
10     end;
11
12  begin
13
14      Qux := 0;
15
16  end A;
```

(b) Package Body for A

```

1  package B is
2
3      function Bar
4          return Integer;
5
6  end B;
```

(c) Package Specification for B

```

1  package body B is
2
3      Narf : Integer;
4
5      function Bar return Integer is
6      begin
7          return Narf;
8      end;
9
10  begin
11
12      Narf := 0;
13
14  end B;
```

(d) Package Body for B

Fig. 4: An exemplary Ada program

For the Ada example illustrated in Figure 4, we show the *static-only dependencies* (i.e., those excluding subprogram calls) in Figure 5a. As we can see, when we do not consider subprogram invocations between packages, there is no statically-determined dependency between A’s package body and B’s package body.

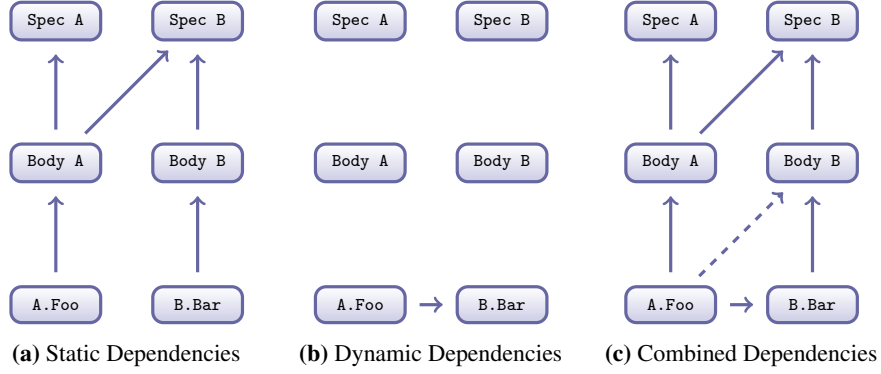


Fig. 5: Types of dependency

We now consider that a test-case t has been created that exercises the subprogram Foo. In this instance, dynamically executing a test-case for the function Foo will then obtain code coverage on both Foo and Bar. After t has executed, we can see that there is a (dynamic) dependency between Foo and Bar (Figure 5b). That is, we have $t \rightarrow \{\text{Foo}, \text{Bar}\}$ in *Covers*.

Finally, the combined dependencies are shown in Figure 5c. As we can see, this is the union of the dependencies from the static and the dynamic data. As shown in Figure 5c, there now exists an *implied* dependency between Foo and the body of B (the dashed arrow between Foo and B). This is because we have a traversal through the dependency graph of:

$$\text{Foo} \rightarrow \text{Bar} \rightarrow \text{B}$$

Consequently, it can be calculated³ that a change to the body of B will impact test-cases that are associated with the subprogram Foo.

3.4 Calculating the Selection

To solve the test-case selection problem, we introduce an ancillary algorithm AFFECTEDSUBPROGRAMS (Algorithm 1). The algorithm is a classic *work-list* algorithm, used to calculate the transitive closure of the dependency tree. For ease, we use *entity* to refer to a specification, body or subprogram.

Our algorithm for solving the test-case selection problem is shown in Algorithm 2. The algorithm takes a given Ada program P , a baseline set of tests \mathcal{T} , the data stored in *Covers* and changed entity c , and returns the set of tests to be re-executed. Once the set of affected subprograms has been computed by AFFECTEDSUBPROGRAMS, AFFECTEDTESTS iterates over these subprograms and selects all tests covering them. These selected tests represent our solution to the test-case selection problem.

We note that AFFECTEDTESTS relies on an external procedure STATICDEP, which calculates the transitive closure of *Contains* and *Uses*.

³where “*impact*” is the inverse relation of dependency.

Algorithm 1 AFFECTEDSUBPROGRAMS

Input: $change : entity$ # change entity
Input: $static_dependencies : entity \rightarrow entity^*$ # static dependencies
Output: $impacted_subprograms$ # set of affected subprograms

```

1:  $impacted\_subprograms \leftarrow \emptyset$ 
2:  $found \leftarrow \emptyset$ 
3:  $new \leftarrow \{change\}$ 
4: while  $new \neq \emptyset$  do
5:    $next \leftarrow new.pop()$  # pops and removes
6:    $found \leftarrow found \cup \{next\}$ 
7:   if  $next$  is subprogram then
8:      $impacted\_subprograms \leftarrow impacted\_subprograms \cup \{next\}$ 
9:   end if
10:   $successors \leftarrow static\_dependencies(next)$ 
11:   $unprocessed \leftarrow successors \setminus found$ 
12:   $new \leftarrow new \cup unprocessed$ 
13: end while
14: return  $impacted\_subprograms$ 

```

Algorithm 2 AFFECTEDTESTS

Input: P # an Ada program
Input: \mathcal{T} # a set of tests
Input: $Covers : \mathcal{T} \rightarrow Subprograms^*$ # test coverage
Input: $c : entity$ # a change in P
Output: $impacted_tests \subseteq \mathcal{T}$ # set of affected tests

```

1:  $impacted\_tests \leftarrow \emptyset$ 
2:  $impacted\_subprograms \leftarrow AFFECTEDSUBPROGRAMS(c, STATICDEP(P))$ 
3: for all  $t \in \mathcal{T}$  do
4:   for all  $m \in impacted\_subprograms$  do
5:     if  $m \in Covers(t)$  then
6:        $impacted\_tests \leftarrow impacted\_tests \cup \{t\}$ 
7:       break
8:     end if
9:   end for
10: end for
11: return  $impacted\_tests$ 

```

Given a change-set comprising of a number of modifications to the program (e.g., multiple package body or subprogram changes), it is possible to encapsulate AFFECTEDTESTS in a higher-level procedure that iterates over each change and collects the aggregate set of affected tests (c.f., *ImpactAnalysis* in [15]).

3.5 On Change Impact for Polymorphic Programs

There has been a lot of consideration in literature [6,19,21] applied to the intricacies of change impact pertaining to object oriented programming. However, in the context of the framework presented, the use of object oriented techniques within Ada does not introduce any further difficulties.

For example, consider a change C that affects the dynamic call tree in a given program P . We will consider the addition or removal of a specialised subprogram in a derived package. If a specialised subprogram is added/removed from a derived package, then the derived specification (upon which P depends) will change, leading to all tests for P , which have code coverage on the derived package, to be re-executed.

If a package body member is changed in the base package, then this will invalidate all tests that have associated code coverage on the derived package, if the derived package has any static/dynamic calls to its parent. If there are no tests that generate any coverage on the base package via calls from the derived package, then a modification to the package global in the base package will have no effect on the derived package's behaviour, and so no tests will be impacted.

Example. Consider two packages Base and Derived, where the specification of Base has two subprograms Alpha and Beta, and that Derived only specialises the subprogram Alpha. We further assume a program P , and associated test, that calls Derived.Alpha, and Derived.Alpha calls Base.Beta. This will create a combined dependency tree as shown in Figure 6 (we use a dashed line to show dynamic dependencies).

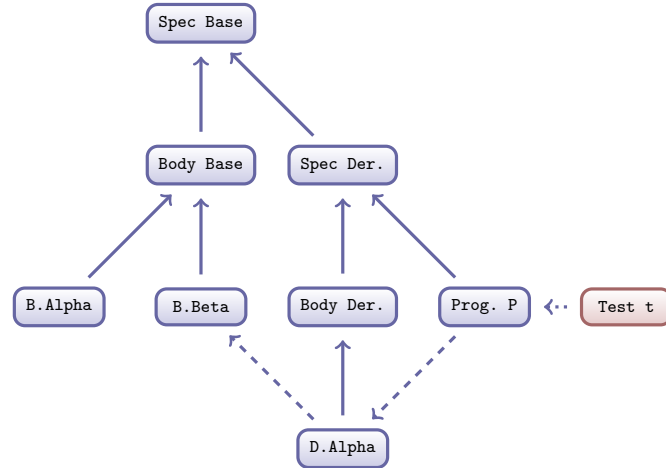


Fig. 6: A polymorphic dependency tree

If we now extended `Derived` such that it contains a specialised version of `Beta`, this would then cause a change in the specification and body of `Derived`, and so we would re-execute any tests that have coverage on the subprogram `Alpha`.

Alternatively, consider a change to a package body member in `Base`. Via the dependency tree from Figure 6, this would then cause any tests with coverage on `Base.Alpha` and `Base.Beta` to be invalidated. Consequently, our test on `Derived.Alpha` would therefore be affected, as per the dynamic coverage collected.

4 Experimental Evaluation

To validate the effectiveness of the technique presented in reducing the number of test-cases to be re-executed, we performed an empirical evaluation comparing VectorCAST with and without change impact analysis.

4.1 Experimental Setup

We considered examples from two sources: “Malaise” and IRONSIDES; we summarise these below. A high-level overview of the packages selected is shown in Table 1.

Table 1: Example specifics

Metric	Malaise	IRONSIDES
Number of files	9	9
Number of lines (incl. comments/whitespace)	654	4,745
Number of non-empty Ada lines	468	3,441
Number of subprograms	46	97
Aggregate complexity metric [25]	94	492
Total number of tests	228	573
Coverage (statement / branch)	68% / 68%	47% / 36%

Malaise. We considered a selection of 9 files taken from [14] – a copy-left repository of Unix-based utilities written in Ada. Some of the packages selected included: `ada_words.adb`, which provides “basic Ada parsing of delimiters, separators and reserved words”; `conditions.adb` that supports “several tasks to wait until unblocked all together or one by one”; and `forker.adb`, an “API to a standalone forker process”.

IRONSIDES. The Internet Domain Name System—or DNS—is an infrastructure whose responsibility it is to translate domain names (e.g., `www.vectorcast.com`) into their corresponding IP addresses (e.g., `67.225.168.102`). IRONSIDES [4], an open-source and freely-available DNS server implemented in SPARK Ada. Via the use of SPARK, the code of IRONSIDES is mathematically proven to be free of defects via the use of formal methods. For the purposes of this evaluation, we consider a subset of 9 files taken from the IRONSIDES “authoritative” (2015-04-15) branch [2].

Testing methodology. To support the empirical evaluation of the presented change-based testing approach, we used VectorCAST to generate automatically three types of test:

- “empty tests” – these are default test-cases generated by VectorCAST that provide empty parameter values to every function;
- “min-mid-max tests” – these call each test with the min, mid and maximum value for each parameter;
- “basis path tests” – we used VectorCAST’s ability to generate automatically basis path tests according to McCabe’s complexity metric [25].

For Malaise, we generated all three types of test; however, to produce a manageable test-suite size, we only generated empty and basis path tests for IRONSIDES (i.e., we did not consider min-mid-max tests). The size of the test-suite and the coverage attained from its execution are presented in Table 1.

For each of the examples, we used VectorCAST to capture the initial state of the software, and then applied modifications to each of the files: namely, we added a “null;” statement to the beginning of a number of subprograms, such that VectorCAST would detect a subprogram-level change. An example of an automated change—highlighted with a box—to the package Ada_Words from Malaise is shown in Listing 1.1.

Listing 1.1: An example modification in the package Ada_Words

```

1  function Is_Delimiter (C : Character) return Boolean is
2  begin
3      null;
4      case C is
5          when '&' | ''' | '(' | ')' | '*' | '+' |
6              ',' | '-' | '.' | '/' | ':' | ';' |
7              '<' | '=' | '>' | '|' =>
8              return True;
9          when others =>
10             return False;
11         end case;
12 end Is_Delimiter;

```

After applying each change, we then performed an “incremental build and execute” inside of VectorCAST, to analyse the code-base and then only re-test the code that changed. To validate the effectiveness of the proposed approach, we executed the same process but without passing the incremental flag to VectorCAST. The version of VectorCAST used for both the incremental and non-incremental runs was the official release of 6.4d (released 2016-02-29).

All of the Ada sources for both of the examples (reproduced under a copy-left licence from both [14] and [2]), the VectorCAST artefacts (e.g., the auto-generated tests) and an “evaluation runner” script are available from [8].

4.2 Results

We performed our evaluation on a 32-bit Linux machine running Fedora 21, with 8 GiB of RAM and a 6-core Intel Xeon clocked at 2.50GHz. The compiler used was “GNAT 4.9.2 20150212 (Red Hat 4.9.2-6)”.

Table 2: Experimental Results

Example	Mode	Units Changed	Subprograms Changed	# Tests Executed	Build + Exec. Time (s)
Malaise	Without CBT	9	21	4,788	1,002.48
	With CBT			165	165.85
IRONSIDES	Without CBT	9	93	53,289	6,986.17
	With CBT			1,347	1,147.14

The results of our evaluation can be seen in Table 2. The column “# Tests Executed” represents the total number of tests re-executed after performing the individual subprogram change, with each change processed separately. Similarly, “Build + Exec. Time” is the total time (in seconds) that VectorCAST took to re-build the test environment, incorporating the current change-set, and to re-run the affected tests.

As we can see, using the change impact analysis presented in this paper, the total number of tests needing to be executed for Malaise was reduced from 4,788 (running all 228 test-cases for each of the 21 changes) to only 165 (re-running only the impacted tests). Similarly, for IRONSIDES, the number of tests required to be re-executed to ensure that no regressions were introduced in the software was reduced by 97%.

We observe that the final column (time) does not scale accordingly, as the auto-generated tests are quick to execute, compared to the higher-cost environment construction. Nonetheless, across both examples, we see an 84% reduction in time to re-test.

Given the size and real-world applicability of IRONSIDES (with its higher performance than commercial DNS servers [4]), we feel that the results obtained would be representative of the benefits achievable in an industrial Ada project.

5 Conclusions

In this paper, we have introduced the first practical approach to applying change impact analysis to the test-case selection problem for Ada. To the best of our knowledge (c.f., [3,12]), ours is the first approach that explicitly uses a combination of both statically derived data and dynamic data from test execution. In safety-critical markets (see, e.g., DO-178C [23] for aeronautics), it is commonplace for there to be a requirement to demonstrate “test completeness” via a code coverage mandate. Consequently, linking a change-impact analysis to data that engineers will already be collecting is advantageous.

We also considered the affect of object oriented techniques when identifying those tests to be re-executed. Considering exclusively static data has previously been investigated [21] and lead to a number of “heavy-weight” frameworks [20]. While simplistic, our approach can also handle changes introduced in the polymorphic hierarchy.

We performed an empirical evaluation of our technique as part of an experimental extension to VectorCAST. Our results on a modest-sized example are promising, but further evaluation is needed.

5.1 Further Work

We have identified a number of additional avenues that could improve on the test-case selection process (at the expense of a heavier technique). The most immediate area to tackle is on the change impact process at a lower level than just subprograms. For example, if the change is constrained to a particular branch of a conditional, then it would be plausible, without a loss of safety, to select only those tests that previously entered the same block.

Our presentation of *AffectedSubprograms*, and calculating the transitive closure of *StaticDep* (Section 3.4), leads us to invalidate all tests when the change is associated to a package specification or a body. When we consider a body-level change that, e.g., changes or introduced a new body-level member variable, this leads us to re-execute more tests than necessary. If we considered only those subprograms that referred to each member variable, we could then be more selective with those that we invalidate.

We leave consideration of how to efficiently handle type modifications at the specification level for further work.

5.2 Closing Remarks

In this paper, we presented, to the best of our knowledge, the first approach for considering change impact analysis for Ada applied to regression testing (outside of [13], which did not consider the test case selection problem). As highlighted above, there are a number of improvements to this technique to further reduce the scope of selected changes. We position this work as the first footing in this direction, and are not discouraged by the modest framework presented.

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